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Quality characteristics and consumer acceptance of diploid and triploid cold smoked Atlantic salmon reared at 5, 10 and 15 °C

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ABSTRACT

This study determined the processing characteristics, textural and colorimetric properties, NaCl content and consumer's acceptability of dry salted cold smoked triploid Atlantic salmon (average weight of 1.6 ± 0.3 kg) reared at different temperatures (5, 10 and 15 °C). As a reference, diploid siblings kept and processed under equal conditions was used. Ploidy did not affect the raw material biometrics but increased holding temperature gave increased blood lactate and decreased muscle pH at point of death. Triploid Atlantic salmon was found to be suitable for cold smoke processing but the differences in quality between diploid and triploid was significant. Cold smoked triploid salmon have on average lower processing yield, higher weight loss throughout processing and storage, and was softer as compared to diploids. Ploidy did however not affect the NaCl content. A consumer test did also distinguish between cold smoked diploid and triploid salmon originally kept at 10 °C. In addition, increased holding temperature was found to give a step-wise lower weight loss during processing and significant darker fillets after cold smoking and storage.

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1. Introduction

Because of the 45 “green production concessions” in Norwegian aquaculture (FOR-2013-06-24-754) the raw material used in production of cold smoked Atlantic salmon (*Salmo salar* L.) today includes triploids. The use of sterile triploids (O'Flynn et al., 1997) in aquaculture is supported by several conservation and management organizations including North Atlantic Salmon Conservation Organization (NASCO) and Food and Agricultural Organization (FAO) (Taranger & Albretsen, 2014, p. 155). The use of triploids will therefore probably increase in the future. Due to the scant knowledge about flesh quality of triploid salmon this may be an unknown challenge for the processing industry. The triploid genetic setup (2n+1) (Benfey, 1999) gives all triploid cells one extra set of chromosomes. This leads to increased nuclear volumes and cell size to accommodate the extra genetic material (Benfey, 1999). Consequently, triploid cells are 30% larger than diploids. Larger cells may induce new challenges related to drip loss and textural properties during processing and storage.

The quality of the raw material is an important factor to produce a high quality smoked product. Triploid Atlantic salmon is known to have lower proportions of superior quality as compared to diploids at slaughter (Fraser et al., 2013; Taylor, Preston, Guy, & Migaud, 2011). The flesh quality of triploid Atlantic salmon is however not well documented, where only a few studies deal with the topic. In a recent study by Lerfall et al. (2017) triploids were characterized by lower blood hematocrit (Hct) and rigor index (Ir), and higher fillet drip loss (DL) and collagenase activity. They were moreover found to be paler and less yellowish compared to diploids. Bjørnevik, Espe, Beattie, Nortvedt, and Kiessling (2004) reported triploids to have more gaping and softer fillets, which can be related to the muscle cellularity (Johnston et al., 2000) where diploid salmon have one third fewer muscle fibers than triploids (Johnston, Strugnell, McCracken, & Johnstone, 1999). The colorimetric characteristics are affected by several parameters including ploidy, genetic variations, variation in muscle density and different seasonal factors (Bjørnevik et al., 2004; Choubert, Blanc, & Vallée, 1997; Johnston et al., 2000). The literature is however not sure about

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which of the mentioned discriminants that are of highest significance for the flesh color. Significant differences in growth, and differences in flesh properties between diploid and triploid Atlantic salmon, shows the importance of increased knowledge about processing characteristics of triploid Atlantic salmon in a cold smoke process.

Cold smoke processing of Atlantic salmon consists of several steps including salting, drying and smoking and the quality of the end product is both affected by raw material characteristics and all processing steps applied (Bencze Rørå et al., 1998; Birkeland, Bencze Rørå, Skåra, & Bjerkeng, 2004; Birkeland & Bjerkeng, 2005; Cardinal et al., 2001; Espe, Nortvedt, Lie, & Hafsteinsson, 2002; Lerfall, Akse, Østerlie, & Birkeland, 2011; Lerfall & Rotabakk, 2016). Salt is usually added to fillets by dry salting or injection of brine where dry salting is driven by diffusion (Dyer, 1942; Rørå, Furuhaug, Fjæra, & Skjervold, 2004). Triploid cells contain by definition 50% more DNA than diploids, which results in increased nuclear volume and cell size compared to diploids (Benfey, 1999). Larger muscle cells in triploid salmon raise questions about how this will affect factors such as product yield, DL, color, salt diffusion and sensory properties throughout dry salting, cold smoking and refrigerated storage. It is important that the technological properties of diploid and triploid Atlantic salmon is as equal as possible. Hence, the aim of the present study was to investigate the processing characteristics, textural and colorimetric properties, salt content and consumer's acceptability of dry salted and cold smoked triploid Atlantic salmon reared at different temperatures. As reference, diploid siblings reared and processed under equal conditions was used.

2. Material and methods

2.1. Fish material and experimental design

The salmon used were of the same selection as presented in Lerfall et al. (2017). In short, triploidy was induced by subjecting fertilized eggs for approximately 6 min to a hydrostatic pressure of 65,500 kPa. Diploid eggs were not pressurized. All eggs were then incubated at 5.8 °C. Following smoltification, both groups (diploid and triploid smolts less than a year old) were transferred to an Institute of Marine Research, Matre, Norway (IMR) sea-pen system (seawater, mass salinity 34 g/kg) in Smørdalen (Masfjord, Norway). At an average weight of 1 kg, both groups were hauled and transported to the experimental facilities at IMR, Matre. The fish were evenly distributed into six 3 m in diameter tanks (9 m^3) with three tanks for each ploidy. The temperature was then adjusted to 5, 10 and 15 °C over 30 d and thereafter held constant over 27–29 d until the fish were slaughtered. After four d of starvation, 60 farmed Atlantic salmon (50% diploid and 50% triploid, average weight of 1.6 ± 0.3 kg) were slaughtered between the 19th and 21st of August 2014. The fish were killed one by one by a sharp blow to the head (approximately 3 min between each fish).

The sampling procedure resulted in a full factorial design with six groups of salmon with different ploidy and water temperature: Group 1, Diploid salmon kept at 5 °C; Group 2, Triploid salmon kept at 5 °C; Group 3, Diploid salmon kept at 10 °C; Group 4, Triploid salmon kept at 10 °C; Group 5, Diploid salmon kept 15 °C and Group 6, Triploid salmon kept at 15 °C.

Immediately after killing, the first five salmon from each group (n = 10) were sampled for a blood analysis of the lactate. All the fish were analyzed for muscle pH, temperature at death, length and whole body weight before the fish was stored, on ice during rigor mortise (60 h). All fillets were thereafter hand filleted, frozen individually, and kept frozen (−30 °C) for 60 d before processing.

2.2. Raw material control

Muscle pH and temperature was measured right after death in the anterior dorsal muscle close to the gills by using a Mettler Toledo SevenGo proTM pH-meter (Mettler Toledo International Inc., USA) connected to an Inlab puncture electrode. Blood samples were immediately extracted from the caudal vein (n = 30). The blood lactate was measured immediately using a Lactate Pro 2 analyzer (Arkray Factory Inc., Koka-Shi, Japan).

2.3. Salting and smoking procedure

After thawing (48 h, 2 °C), all fillets were covered with sodium chloride (fine-refined salt, minimum 99.8% NaCl) and stored on grids in a refrigerated room (20 h, 2 °C). All fillets were thereafter rinsed in cold water (approximately 8 °C) to remove excess of NaCl. Salt-cured fillets of all six groups were then randomized on grids, dried separately for 60 min, followed by four circles of 50 min smoking (beech chips) and 10 min drying (23 °C, relative humidity: 75–83%, air velocity: 0.4–0.8 m/s) according to Birkeland, Skåra, Bjerkeng, and Rørå (2003). Vacuum packaged fillets from all protocols were stored in a refrigerated room (2 °C) for 28 d.

2.4. Processing yield, weight loss and NaCl content

The weight loss (WL) at each processing step and throughout storage were calculated as the difference in fillet weight between raw, and salted and smoked fillets, respectively (Lerfall, Bendiksen, Olsen, & Østerlie, 2016). Moreover, the WL during 28 d refrigerated vacuum storage was calculated as the difference in fillet weight between smoked fillets and fillets stored 28 d. The processing yield was moreover calculated as % smoked fillet compared to the initial fillet weight.

Content of NaCl was analysed on samples of minced smoked salmon. The salt content was determined conductivimetrically after a method described by Birkeland, BenczeRørå, Skåra, and Bjerkeng (2004) and analyzed on a Dicromat 11-6 Salt Analyser (PCL Control Instrumentation Ltd., Leicester, UK).

2.5. Textural properties

Instrumental textural analyses were performed in the dorsal part of the Norwegian quality cut (NQC) using a Texture Analyzer TA-XT2 (SMS Ltd., Surrey, England) equipped with a 30 kg load cell. A flat-ended cylinder probe (10 mm diameter, type P/1SP) was used. The force-time graph was recorded by a computer equipped with the Texture Exponent software for windows (version 6.1.7.0, SMS), which was also used for the data analyses. The analyses were performed in duplicates (average values were used for data analyses) of each fillet at the end of the storage period (28 d post smoking). The resistance force (N) was recorded with a constant speed of 5 mm/s, and the force required to press the cylinder down to 80% of fillet thickness was used to describe firmness.

2.6. Colorimetric properties

Surface color (CIE, 1994) was measured on a DigiEye full system, VeriVide Ltd., Leicester, UK of the raw material, after each processing step, and after 28 d refrigerated storage. The software Digipix (version 2.7) was used to calculate $L^*a^*b^*$ values from RGB values obtained from the fillet image.

2.7. Consumer acceptance

Participants in the consumer test were recruited in the canteen

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